



Electrodeless Z-Pinch™ EUV Source for Metrology Applications

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Agenda

- Overview of Mask Inspection
- Energetiq EUV Metrology Source
- Next Generation Mask Inspection Requirements
- Opportunities for a high brightness EUV source



Overview of Mask Inspection

Role of EUV mask

Scanner design – multilayer mirrors, reflectivity ~ 70%

~ 1% or less of photons at source incident on wafer

Mask

Mask is a multi-layer mirror with an absorber pattern on the surface.

4x demagnification from mask to wafer.

Is that a defect??

Will it print??

6-mirror projection optic

collector

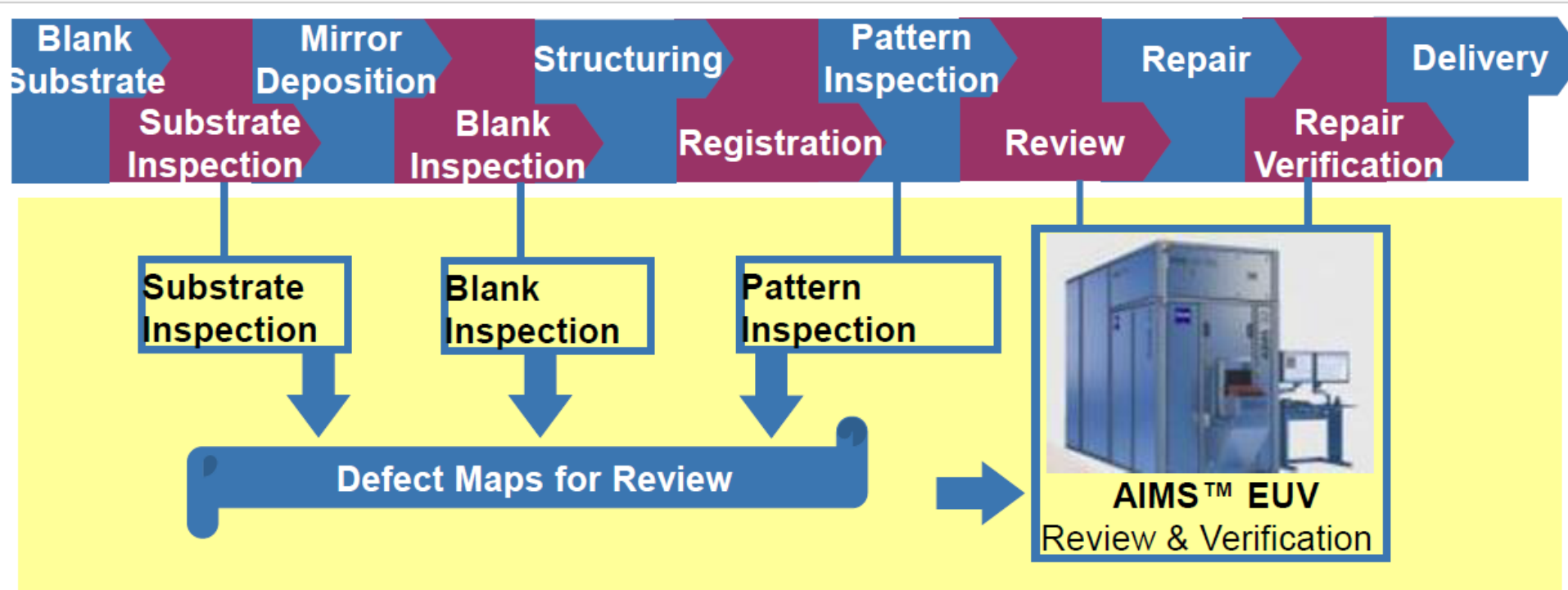
light source

Resist-coated Wafer

Understanding and controlling mask defects is critical to success!

Diagram ASML

Metrology for EUV Mask Manufacturing

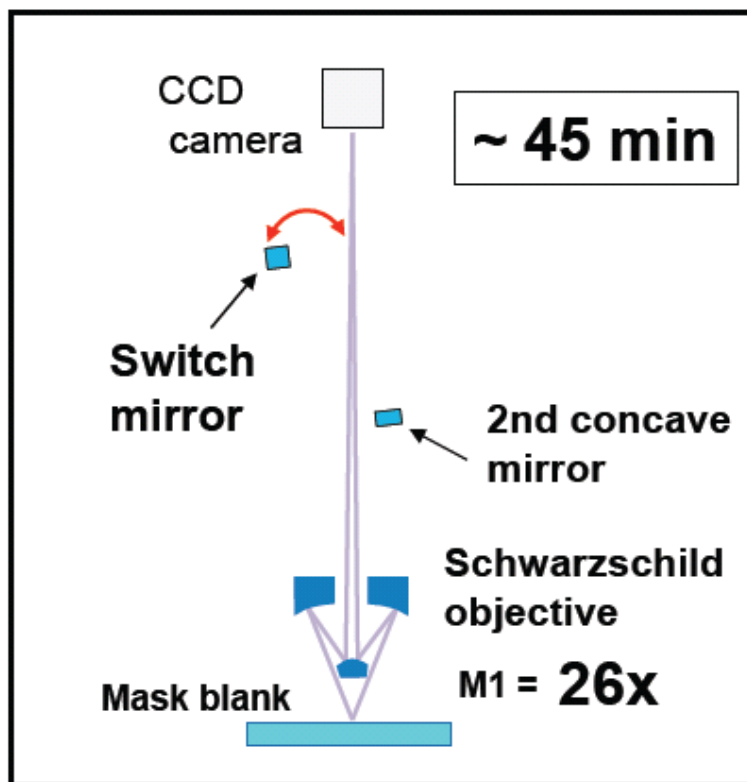


Actinic Metrology is required to predict printing behaviour of hot spots in the mask pattern

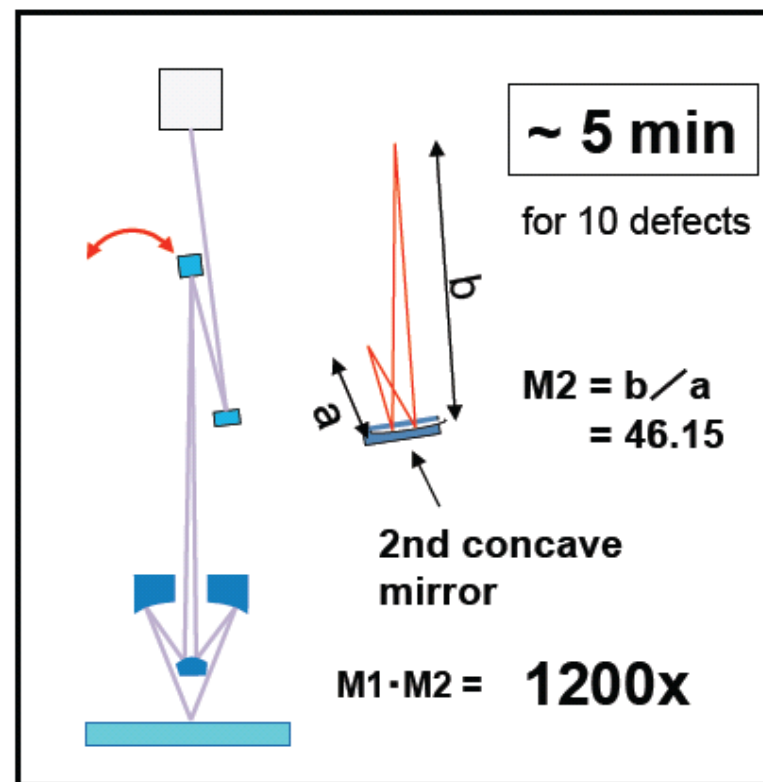
Mask Blank Inspection

System Design

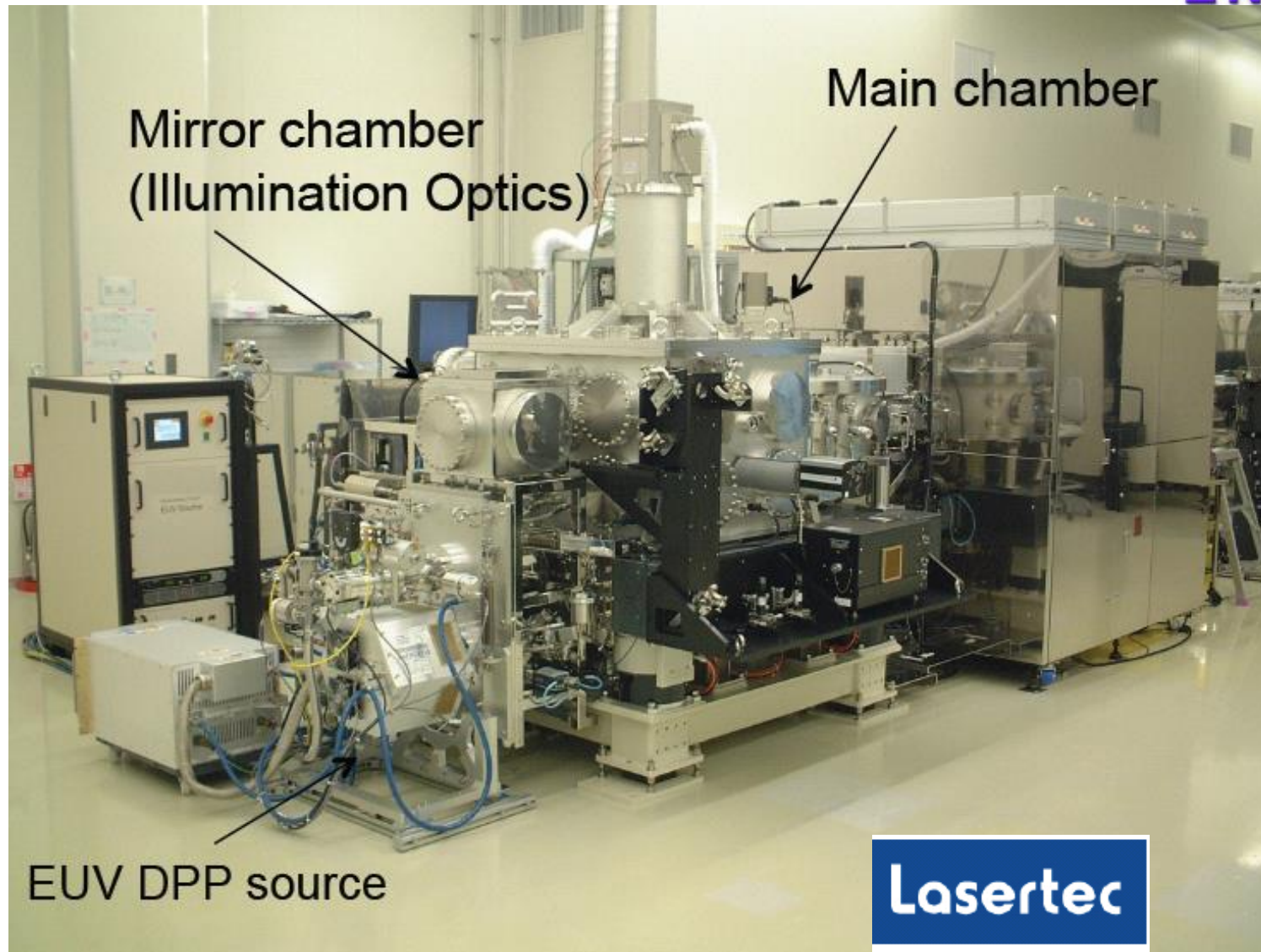
Inspection mode



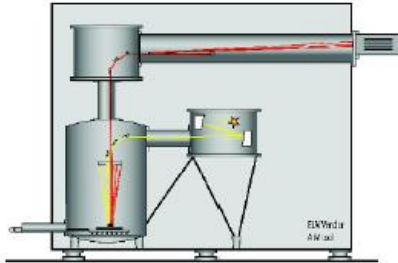
Review mode



Inspection and review in one system



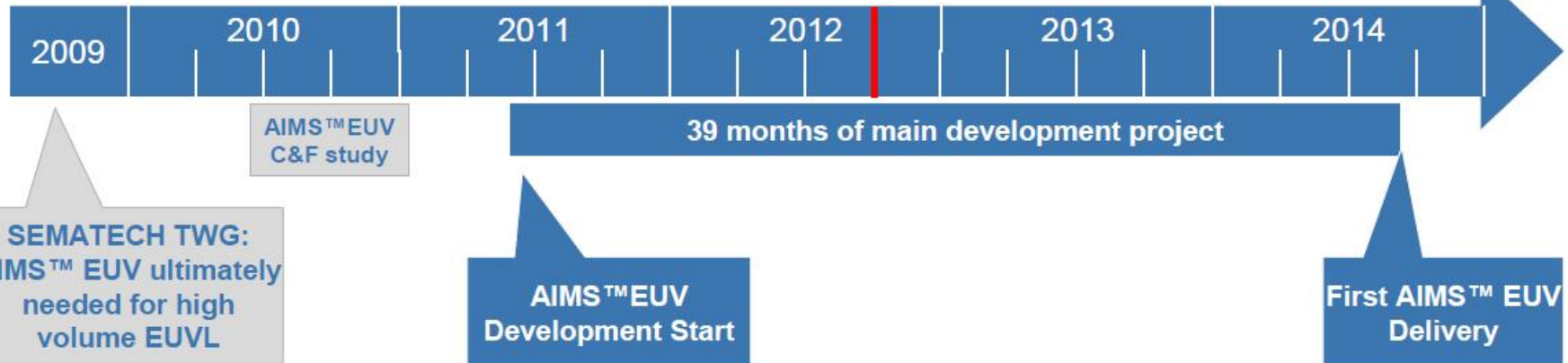
Schedule to EUV mask defect printability review established: AIMS™ EUV development program started



Ideas and concepts

Detailed design

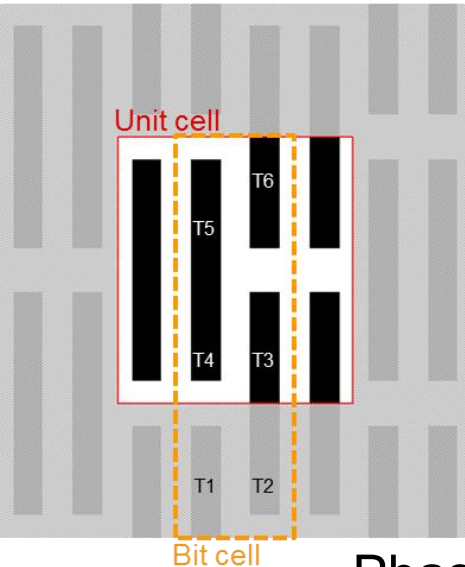
Delivery



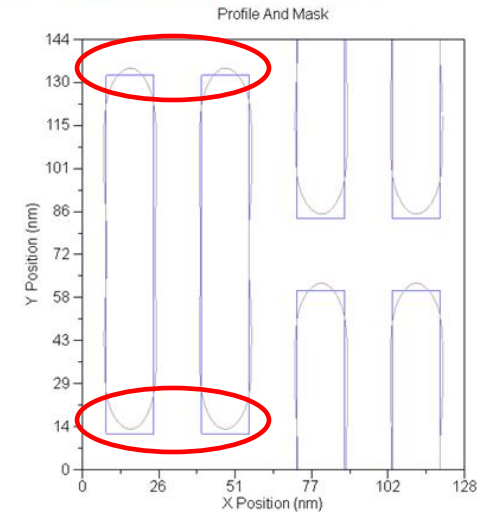
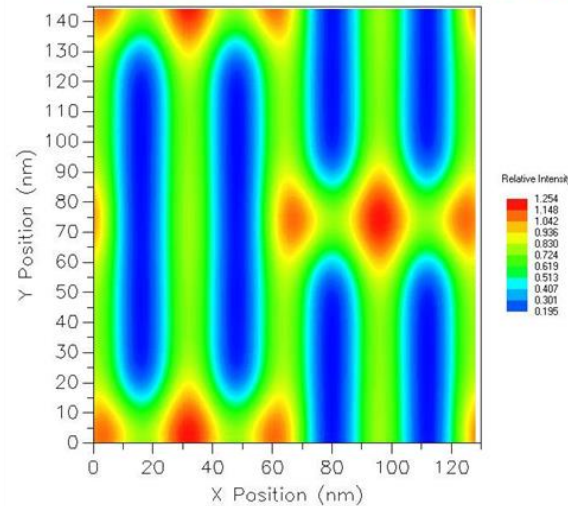
Carl Zeiss SMT is currently building a first generation AIMS tool supporting the 16nm node. For the 11nm node, an extension will be required.

AIMS™ Applications

Accurate 0.33NA EUV scanner emulation: Pattern Mask Review:

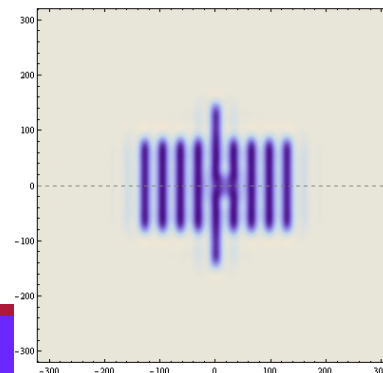
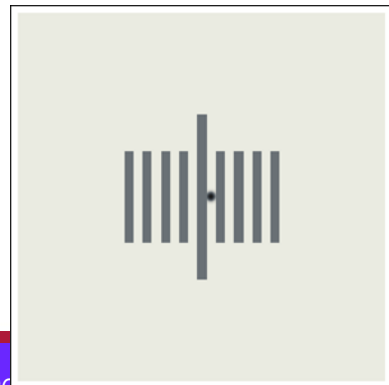


This model shows a 16nm L/S with a 2.3nm image pixel for reference.



Pattern shift
due to
Shadowing

Phase defect

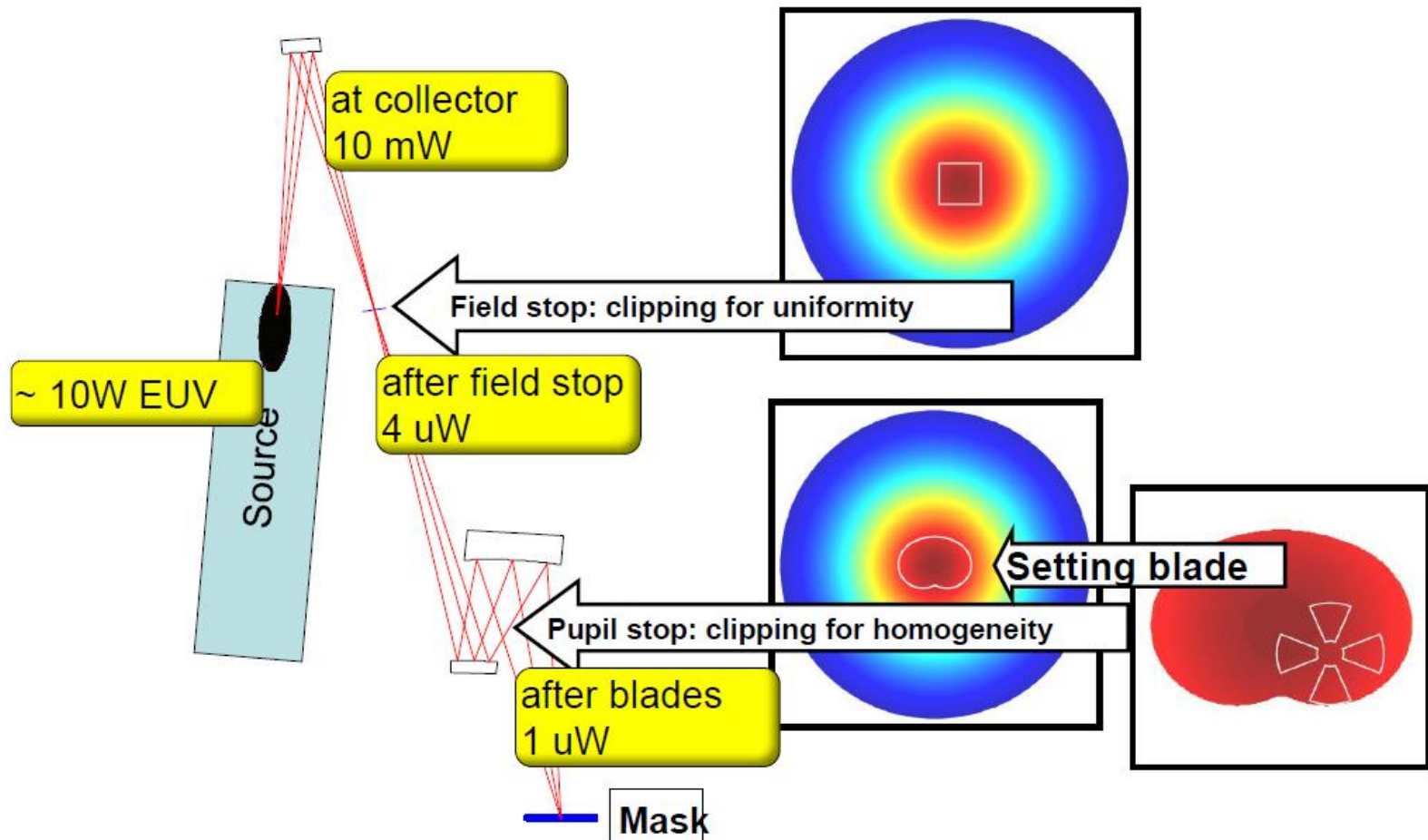


- 16nm Line/Space, with 4nm H x 40nm FWHM phase-defect (23nm SEVD), 0.33NA13.5nm, 60° dipole-quasar 0.3/0.9 σ .

Lines Bridged

The Illumination Concept

Source Brightness is important



Most of the EUV radiation is lost due to geometrical clipping.
To maximize the photon count within the limited etendue,
Brightness is more important than source power!

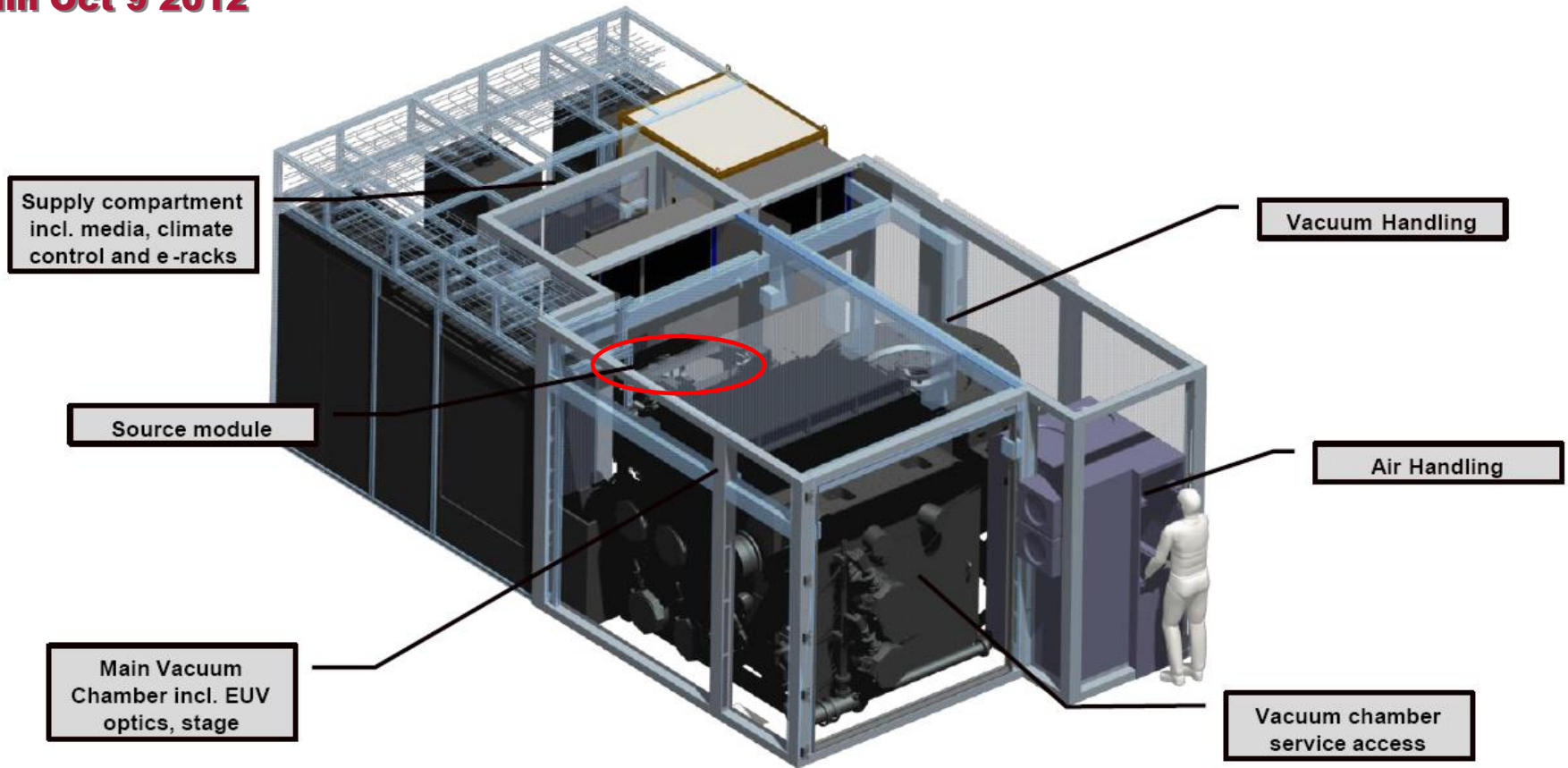
Preliminary layout of the AIMS™ EUV



Light Sources for EUV Mask Metrology

Heiko Feldmann, Ulrich Müller

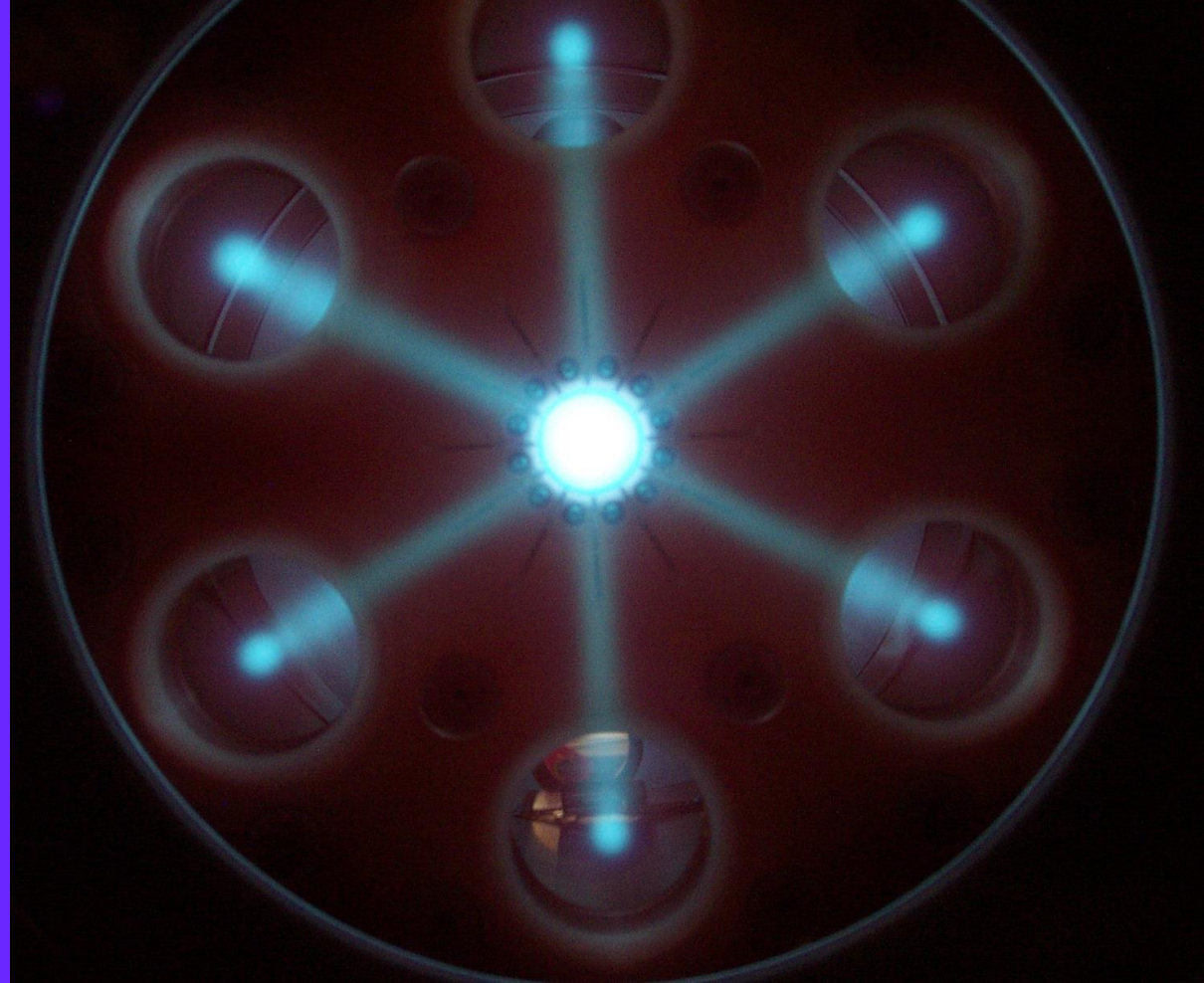
Dublin Oct 9 2012



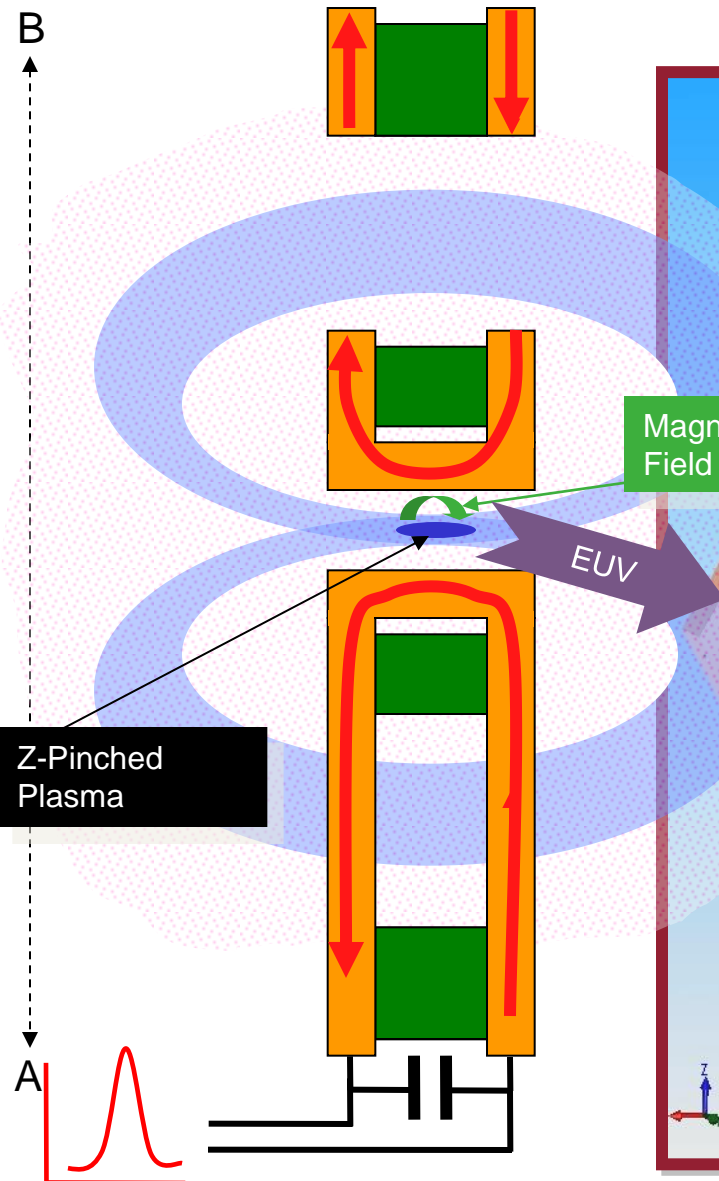
1

What parameters of the EUV Source are critical for Mask Inspection?

- Brightness
- Stable plasma position
- Energy stability – Pulse to Pulse
- Cleanliness
- Uptime/Reliability



Our solution



Energetiq: Electrodeless Z-Pinch™ EUV Source

- 'Slow' pulse from modulator.
- Capacitor banks charge up.
- Outer core saturates. Impedance $\Rightarrow 0$
- Capacitor discharges. (Pulse compression)
- Inner core couples current pulse to plasma loops.
- Pulse in plasma current \Rightarrow Z-pinch!

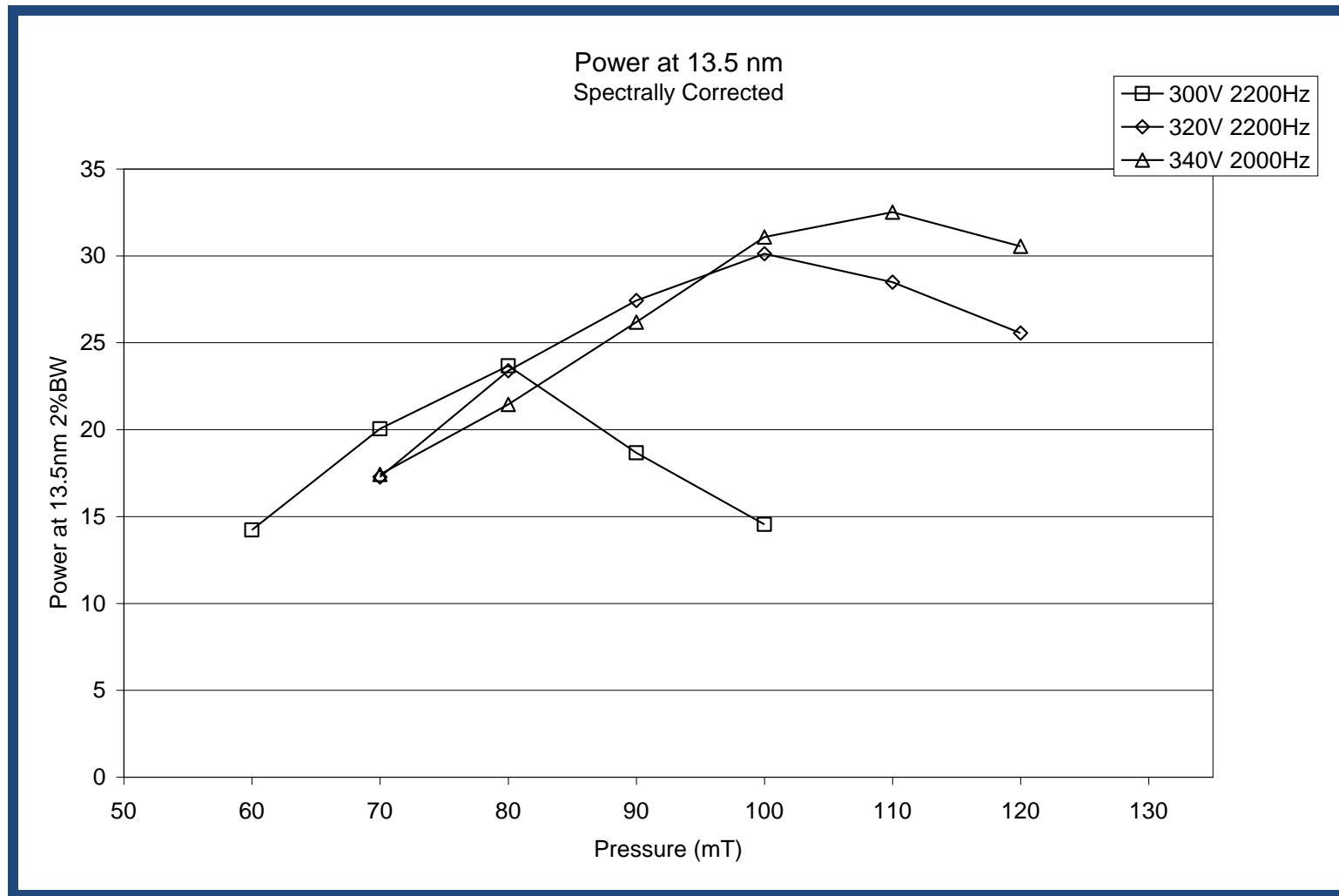
capacitor banks not shown

EUV Source Field-Proven Reliability

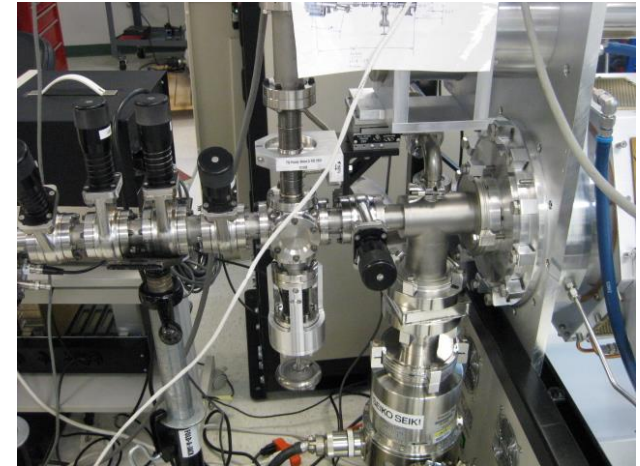
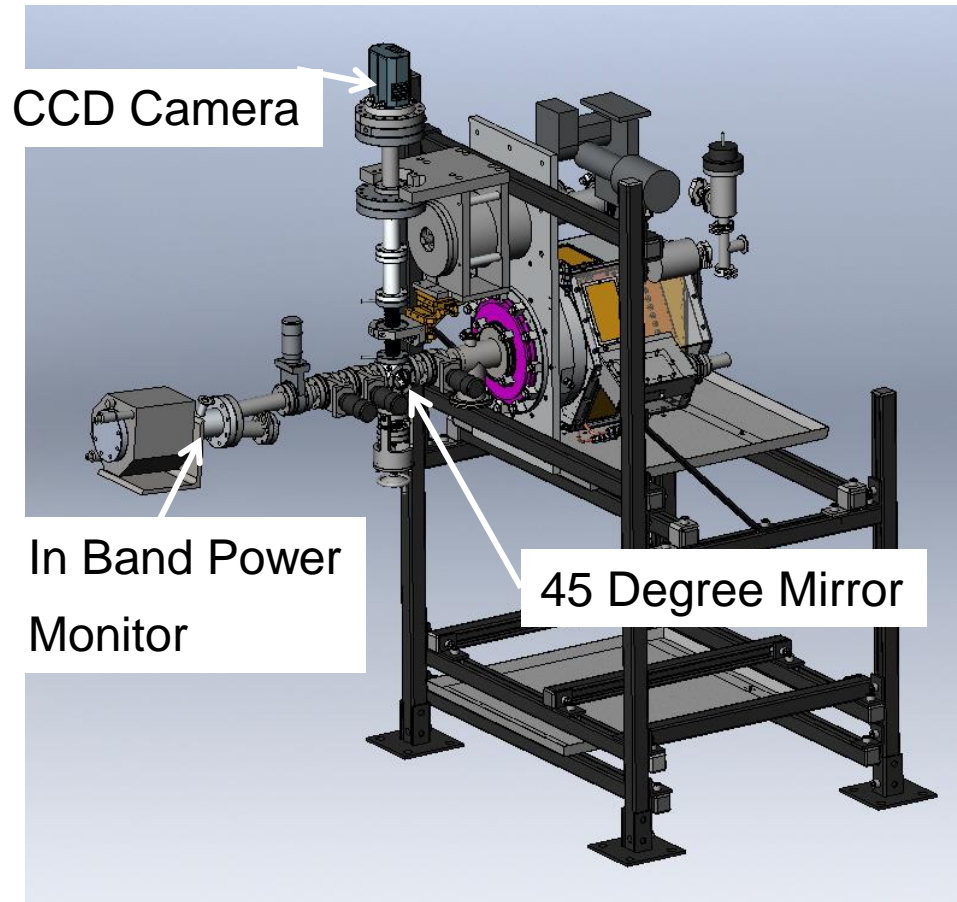
- More than 25 sources operating in the field
- Installations in Japan, Europe and USA
- Systems operating 24/7 with minimal downtime
- Systems integrated into tools for R&D and pre-production
 - Actinic Inspection
 - Resist Outgassing
 - Mask Contamination
 - Optics Testing



EQ-10HP EUV Power

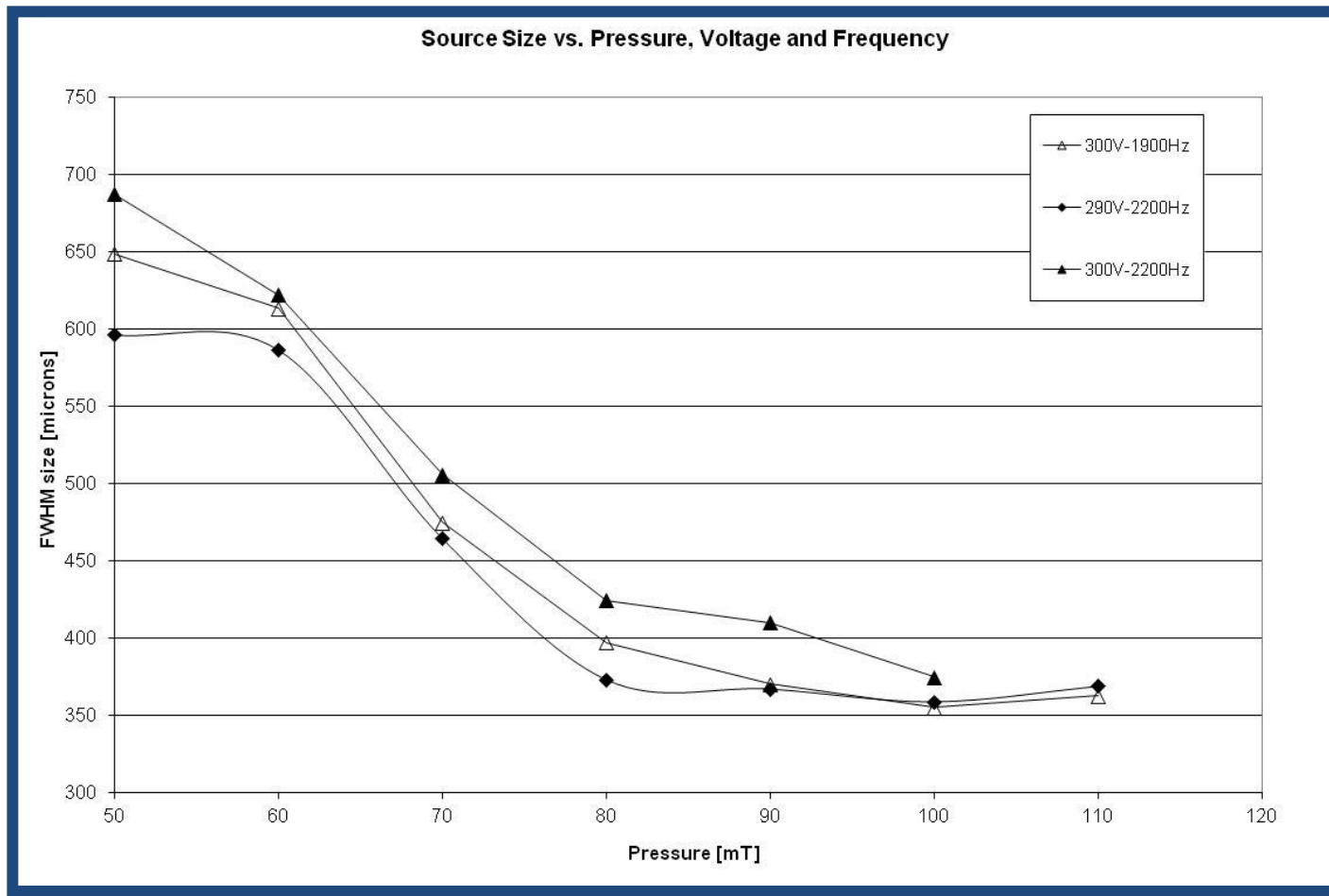


New Dual Diagnostic Brightness Measurements



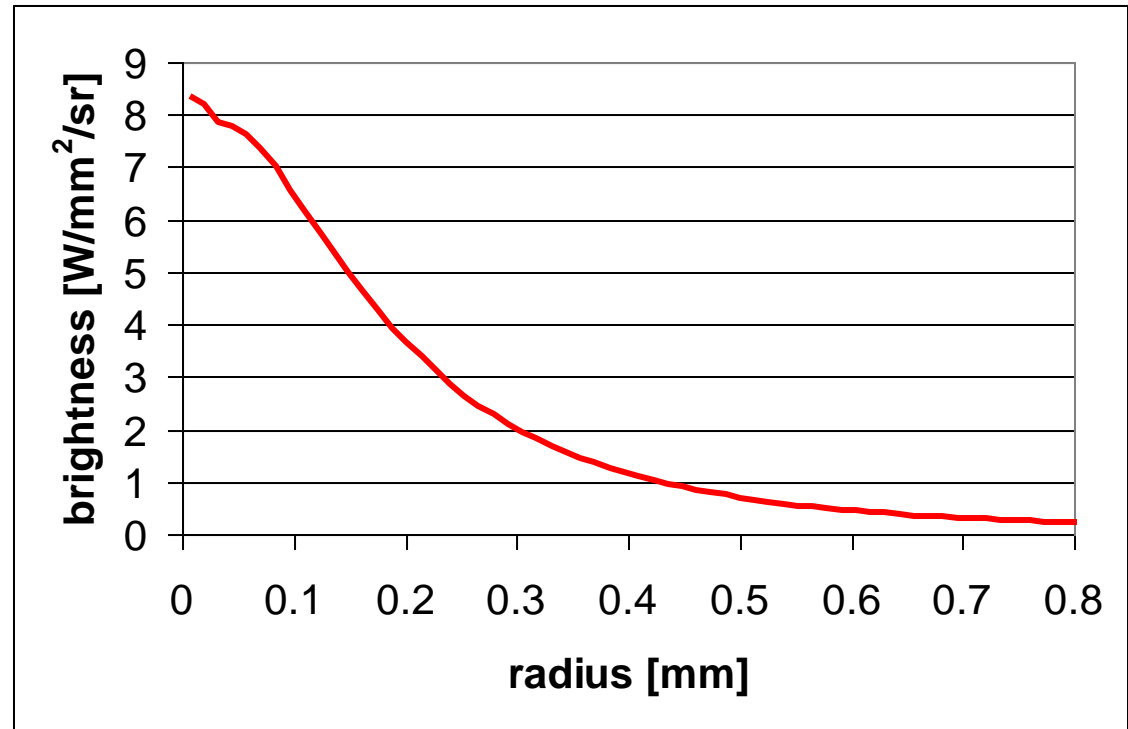
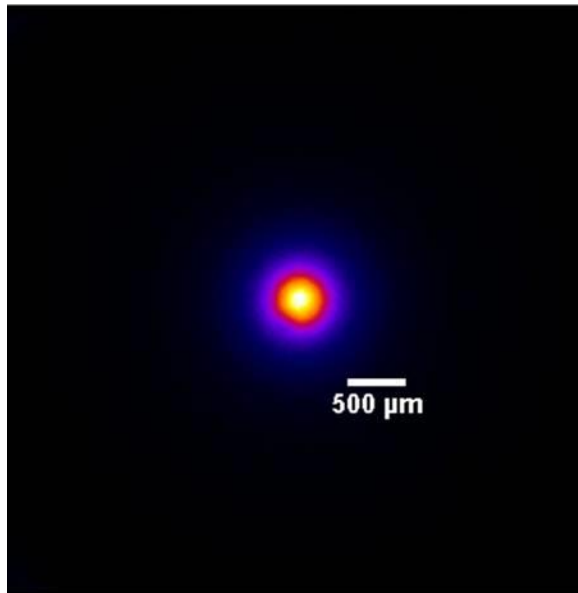
EUV Power Monitor is
Calibrated at NIST

EQ-10HP EUV Plasma Size

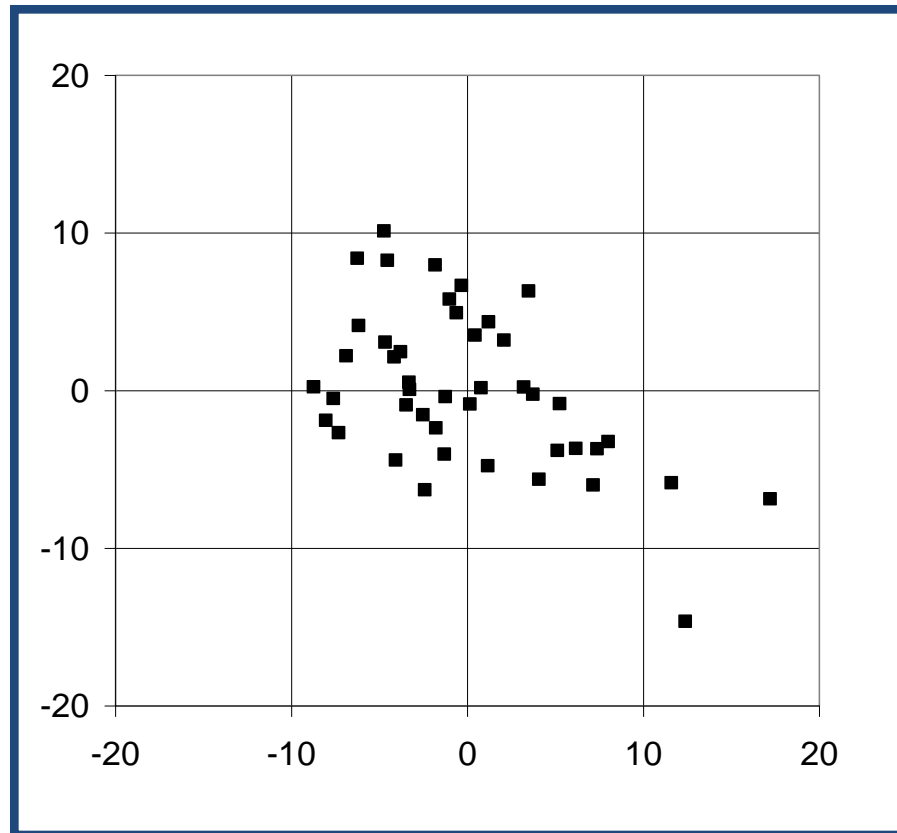


Xenon Source Performance: EUV brightness

- Power plus imaging measurement give brightness (units of Watts/mm²/steradian) – critical for inspection applications

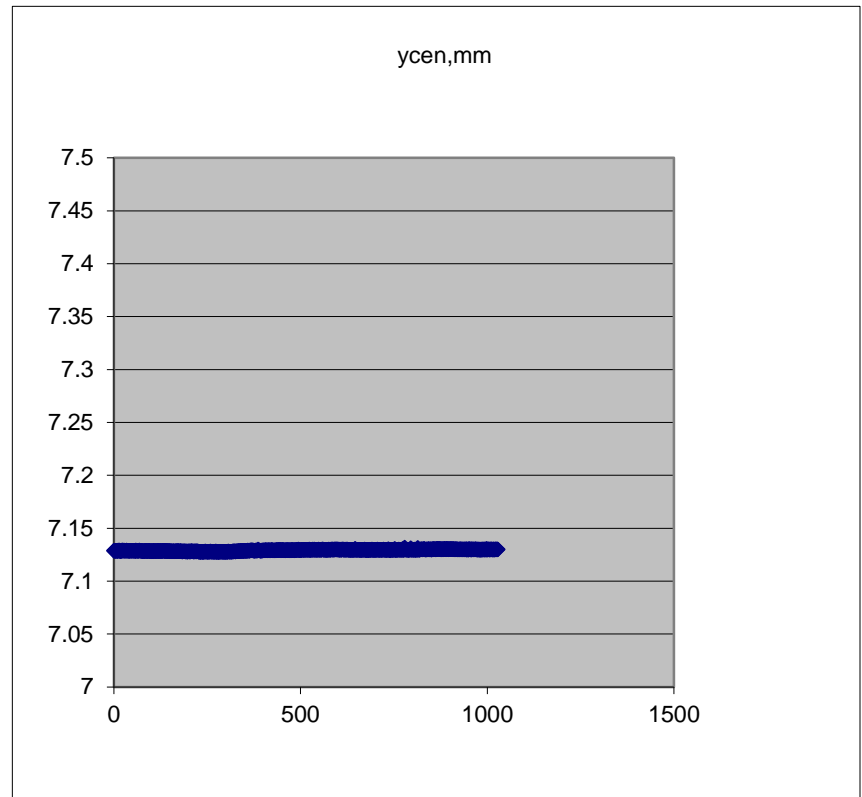
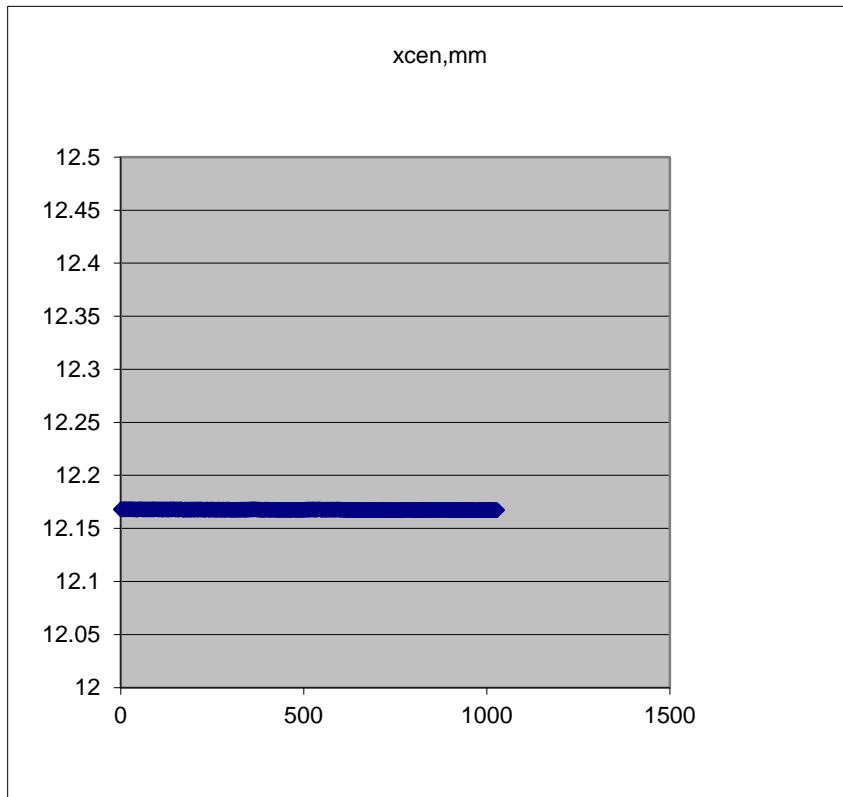


Long Term Stability in Plasma Position



- 1 image per hour for 44 hours continuous operation
 - Position: $\sigma_x = 5.8 \mu\text{m}$ and $\sigma_y = 5.0 \mu\text{m}$

Short Term Plasma Stability in X and Y



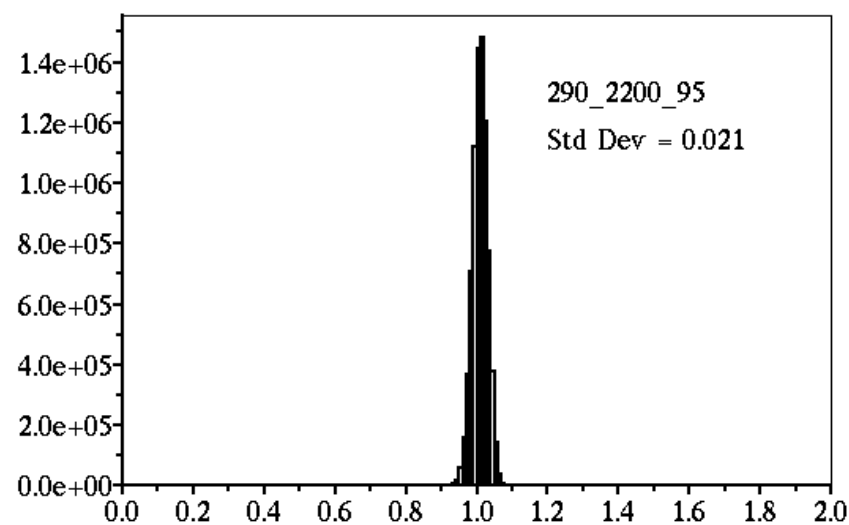
1 image every 3 seconds = 50 minutes data

Pulse stability at varying operating conditions

Conditions:

V_Hz_mT	Stability
280_2200_100	0.0179
280_1900_90	0.0190
280_1900_70_2	0.0215
280_1900_110	0.0223
280_2200_80	0.0268
300_2200_80	0.0359
320_1900_100	0.0371
320_1900_80	0.0402
320_1900_60	0.0667
300_2200_60	0.0705

Histogram of 7918809 values; normalized to unity average





HVM EUV Mask Inspection Requirements

IEUVI Metrology Source Specifications

Key Specifications

- Radiance: ~40 – 100
- Temporal Instability $\leq 3\%$
- Position Instability $\leq 3\%$
- Size Instability $\leq 1.2\%$
- Etendue: Use dependent

❖ AIMS EUV

❖ Pattern mask inspection

❖ EUV mask blank inspection

Specs evolve over time! (2011)

M. Goldstein, D. Chan, "Joint IEUVI and EMI Source Technical Working Group (TWG)" IEUVI Meeting at the 2011 International Symposium on Extreme Ultraviolet Lithography, October 17-19 Miami, FL.

!	Specification	Requirement
	HVM Prototype Available	Q3'2014
	Wavelength [nm]	13.5
	Repetition Rate [KHz]	≥ 10
	Pulse Duration [nS, FWHM]	≥ 10
	Continuous Operation, $\tau \geq 100$ hrs	100%
!	In-Band Brightness B_1 [W/mm ² /Sr] Pre-SPF B_2 0.5 Sec. AVG B_3	$\geq 100 @ E_1$ $\geq 40 @ E_2$ $\geq 80 @ E_3$
!	Etendue E_1 [mm ² Sr] E_2 (Max and min size TBD) E_3	5×10^{-4} 1.5×10^{-2} 4×10^{-3}
	Power, $\pm 1\%$ BW [mW]	No Spec. For info only.
	Inhomogeneity [% , within used Etendue]	$\leq 5\%$ spec $\leq 1\%$ may be needed.
!	Position Instability [% , $3\sigma_{\text{center}}/\text{FWHM}$] Avg over τ seconds. $3\sigma_{\text{center}}/\text{FWHM}$ over 1 hour	$\leq 3\%$ Pos. $\leq 1.2\%$ Size $\tau = \text{TBD}$ (10 to 300ms).
	Temporal Energy Instability [%] 3σ , Avg 10mS windows. 3σ from 1 hour of data.	$\leq 3\%$
	Pulse timing error (Jitter)	$\leq 1 \mu\text{S}$ Jitter
	SEMI E10 Availability [%]	$\geq 95\%$, 2015 Roadmap TBD
!	Cleanliness (Source supplier to propose concept)	100%
	Footprint [L x W x H, meters]	$\leq 3 \times 3 \times 2$
	Control, minimum on period.	$\leq 100 \text{ mS}$
! = Must have spec. Tradeoffs possible in other specs.		

Light Sources for EUV Mask Metrology

Heiko Feldmann, Ulrich Muller

Dublin Oct 9 2012

We are looking for a next generation source for AIMS EUV based on the key parameters*

- Stability
 - Plasma position <3% of FWHM
 - Energy stability <3.5% (3σ) pulse-to-pulse
- Brightness
 - > 30W/mm²/sr (minimum)
 - >100 W/mm²/sr (target)
- Cleanliness 100%
- Availability / Reliability

These are our key guiding parameters for the search and early selection.
They will be modified and extended for different source concepts individually.

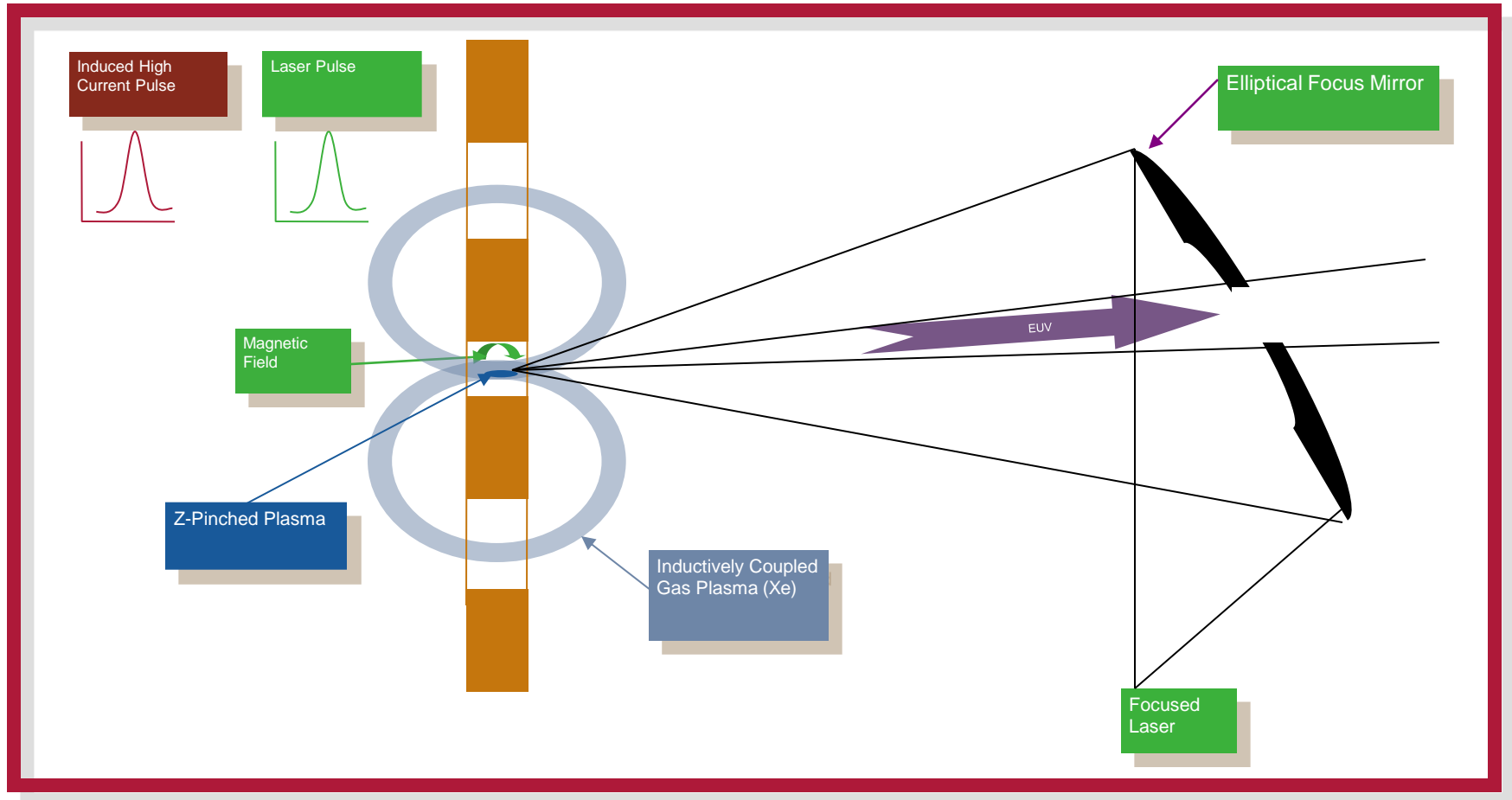


Opportunities for High Brightness EUV Source

Introduction of Laser to Xenon Z-Pinch

- Standard LPP uses a cold Xe or Sn target
 - Laser must ablate the cold target, then ionize it, and finally heat the resulting plasma to the 20-30 eV range
 - These systems produce a very bright plasma on a single pulse basis, but stability can be an issue leading to lower average brightness in a collected beam.
- The Energetiq EQ-10 has a xenon plasma pinch with extremely stable position allowing it to be an excellent target for laser heating
- By coupling a high energy pulse laser to the xenon pinch, EUV brightness will be greatly enhanced

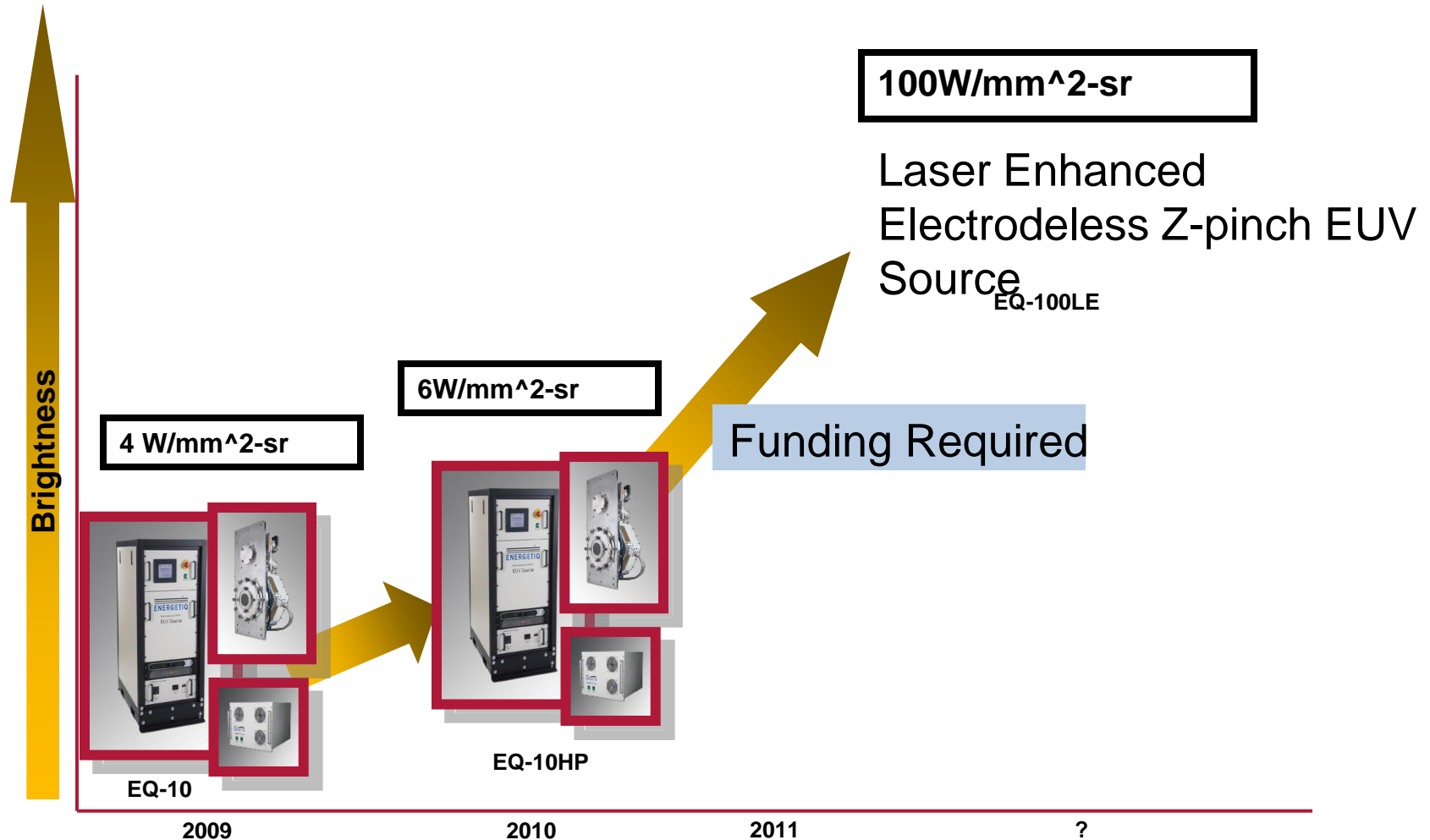
Laser Enhanced Electrodeless Z-Pinch EUV Source



Fundamental Concept:

- Make a cold dense Xe plasma target. (high pressure > 0.4 torr)
- Assume pinch compression and total coupled power are similar to our usual plasma
 - Uncompressed number density $\sim 1.4e16$
 - Compressed density $\sim 3.2e18$
 - $T \sim 5$ eV, $Z=4$, $n_e \rightarrow 1.2e19 \rightarrow$ same total energy as our usual plasma
- Hit plasma with YAG laser (1060 nm) at moderate NA, spot size ~ 50 microns or less.
- Reheat plasma to 25 eV with laser pulse in tiny volume
 - $Z \rightarrow 10$, $n_e \rightarrow 3.2e19$
- Radiation/unit volume \sim brightness increase of order 100.
 - Estimate should give a brightness of $> 100 \text{ W/mm}^2\text{-sr}$

Energetiq EUV High Brightness Roadmap



Summary

- Mask Inspection is critical to the success of EUV Lithography
- AIMS equipment is needed shortly
- Current EUV source technology is sufficient for initial mask inspection tools
 - AIMS and Blank Inspection
- Source development is needed for HVM Mask Inspection tools
 - Stability and higher brightness is a requirement

Acknowledgements

- The team at Energetiq...
- Our valued customers...
- Our excellent partners and collaborators...



Thank You

*Debbie Gustafson, Matt Partlow,
Paul Blackborow, Steve Horne,
Matt Besen, Don Smith*